THE TESTING OF A NEW METHOD FOR COLLECTING RATING OF PERCEIVED EXERTION DATA DURING TREADMILL EXERCISE

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ABSTRACT

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The purpose of this study was to test a new method for obtaining ratings of perceived exertion (RPE) during treadmill exercise. The new method utilized an analog dial fixed to a potentiometer on which a range of 0 to 80 ohms could be elicited. Subjects for this investigation consisted of 26 members of the University of Wisconsin-La Crosse baseball team. The Ss were randomly split into two groups. The first group ($n = 13$) utilized the Borg scale, and the second ($n = 13$) the analog dial. Each S participated in a Bruce protocol maximal graded exercise test. At 30 sec intervals, RPE, HR, and VO_2 were obtained. A correlational analysis was then performed between the variables for both the analog dial group and the Borg scale group. The results showed a significant ($p < 0.05$) relationship between RPE and HR ($\rho = 0.92$), RPE and VO_2 ($\rho = 0.93$), and HR and VO_2 ($\rho = 0.89$) for the analog dial group. Likewise, for the Borg scale group, results showed a significant ($p < 0.05$) relationship between RPE and HR ($\rho = 0.85$), RPE and VO_2 ($\rho = 0.91$), and HR and VO_2 ($\rho = 0.92$). F tests ($26,26 = 2.58$: alpha $= 0.02$) revealed no significant differences between Borg scale and analog dial correlation coefficients. It was concluded that analog RPE correlates significantly with the physiological variables of HR and VO_2, but not significantly better than Borg scale RPE. Also, the analog scale shows a curvilinear relationship with percent of the graded exercise test completed.

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INTRODUCTION

Physical activity has long been promoted as a method of maintaining quality of life and health (1,2). Exercise scientists have developed many methods of obtaining physiological variables in order to monitor physical activity and exercise test and train individuals. This acquisition of physiological data makes it possible for people to optimize their activity levels for maximum health and fitness.

Some of the physiological variables obtained during exercise include measurements of heart rate (HR), oxygen consumption (VO_2), blood pressure, ventilation, and blood lactate concentration. Many of these measurements, require sophisticated equipment and trained personnel (2). Ratings of perceived exertion (RPE) scales are often used as an adjunctive measure to physiological functioning, or can be analyzed as a separate measure.

Rating perceived exertion involves the detection and interpretation of sensations arising from the body during physical exercise (23). In other words, it is a way to collect subjective data on how a person feels during exercise.

Many RPE scales have been developed (4,6,15,23), but the most notable and highly used is Borg's 15 point rating scale of perceived exertion (4). In an experimental study developed by Borg (5), this scale and three others were compared. It was concluded that there is a fundamental relationship between physiological and psychological indicators of stress.

The Borg scale is the most widely used tool to measure perceived exertion during exercise (3,10,11,12,13,17,22,25,26,28,29,30). One potential shortcoming to this scale is its limited (15 point) range of numbers. Fifteen points may not be enough to adequately describe how a person is feeling during exercise. Because of this limitation, an analog scale may be more appropriate for the assessment of perceived exertion.

Analog scales provide ratio data. Characteristics of a ratio scale include data categories that are mutually exclusive, have a logical order, and are scaled according to the amount of the characteristic they possess (14). Furthermore, equal differences in the characteristic are represented by equal differences in the numbers assigned to the categories, and the point zero reflects an absence of the characteristic. When using an analog scale to rate perceived exertion, each number represents a different sensation.

Perceived sensations, as measured on the analog scale, increased in intensity from 0 ohms, which indicated a perception of minimum effort, to 80 ohms, which indicated a perception of maximal exertion. A rating of 40 ohms, which was exactly halfway between the minimum and maximum numbers, represented a perception of exertion which was halfway to maximum.

Data collected from analog scales are highly detailed. Fractions of numbers may be elicited by subjects. These data provide richer and more exact information than those collected from other types of scales. The examination of analog data may then make it easier to distinguish subtle changes and patterns in the perception of exertion.

Patterns of exertion were examined by Noble, Borg, Jacobs, Ceci, and Kaiser (21), who performed a study in which perceptual ratings exhibited a quadratic (square) trend. This nonlinear trend may be more preferably investigated with an analog scale.

The purpose of this investigation was to test a new method of obtaining RPE during graded treadmill exercise by correlating RPE values with HR and VO_2. This new method utilized data from an analog dial which was compared with data obtained from a traditional 15 point Borg scale.

METHODS

Subjects

Subjects for this investigation consisted of 26 male volunteers, between the ages of 18 and 23 (20.54 ± 1.3 years). The mean height was 181.71 ± 6.2 cm, and the mean weight was 82.83 ± 9.3 kg (see Table 1). All subjects were members of the University of Wisconsin-La Crosse baseball team. The sample was randomly split into two groups, 13 in the Borg scale group and 13 in the analog dial group.

Table 1. Descriptive characteristics of subjects

	Mean	Standard Deviation	Range
Age (yrs)	20.54	1.3	18-23
Height (cm)	181.71	6.2	170.18-193.04
Weight (kg)	82.83	9.3	65.45-102.27

Pretest Procedures

One to two days prior to participating in the study, subjects were given a written reminder (see Appendix A). Prior to participation ... data collection, a health history questionnaire was administered (see Appendix B) and voluntary informed consent was obtained (see Appendix C). Subjects were then weighed and measured for height, and given verbal instructions about the test.

Test Procedures

Testing took place in the Human Performance Laboratory on the campus of the University of Wisconsin-La Crosse. Each subject underwent a maximal treadmill graded exercise test using the Bruce protocol (see Table 2). Every 30 seconds during the test, VO_2, HR, and RPE were obtained.

Table 2. Bruce treadmill protocol

Stage	Minutes	Speed (mph)	Grade (%)
1	0-3	1.7	10
2	3-6	2.5	12
3	6-9	3.4	14
4	9-12	4.2	16
5	12-15	5.0	18
6	15-18	5.5	20

Expired air was analyzed for determination of VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) by open circuit spirometry using the Q-Plex I automated gas system (Q-Plex, Quinton Instruments, Bothell, WA). Calibration prior to each test was done using known gas concentrations previously determined by the micro-Scholander technique. Volume calibration was performed with a 3.002 liter syringe at various flow rates. Heart rates were recorded using Polar Vantage XL heart rate monitors (Polar-CIC Inc., Port Washington, NY).

Rating of perceived exertion was recorded using either the Borg 15 point scale or the analog dial (see Appendix D). The subjects who used the Borg scale chose a number by pointing to the scale which was placed in front of them (see Appendix E).

The analogue dial was positioned next to the subject's dominant hand. It consisted of a 0-100 ohm Radio Shack potentiometer dial attached to a Micronta 22-194 digital ohm meter (Tandy Corp., Fort Worth, TX) so that a range of 0-80 ohms could be elicited. The 180 degree dial was anchored with the key terms "rest" to the left and "max" to the right. Each subject adjusted the dial every 30 seconds when the tester said "RPE" (see Appendix F). After adjustments were made, ohm values were recorded by the tester.

Statistical Analysis

Data were analyzed using the SPSS 6.1.2 for Windows 3.1 statistical package. Descriptive statistics were run to characterize the subjects, and Fisher's z transformations were executed to test all data for normality. Spearman rho correlations (14) were performed between the variables HR, VO_2, and RPE. The level of significance was set at $p < 0.05$. F tests were performed to check for significant differences between the Borg and analog dial correlation coefficients. A Bonferoni adjustment was performed to adjust the alpha level in order to avoid the accumulation of Type I error.

RESULTS

Fisher's z transformations revealed that the data were not sufficiently normal to administer Pearson product-moment correlations, therefore, data was analyzed using Spearman rho correlations. The correlation coefficients between RPE, HR, and VO_2 for both Borg scale and analog dial groups are presented in Table 3. All correlations were significant and represented strong relationships between variables.

The correlations between RPE and HR, and RPE and VO_2 were 0.85 and 0.91, respectively, for the Borg scale group. For the same group, the correlation between HR and VO_2 was 0.92. Similarly, the correlations for the analog dial group were 0.92 between RPE and HR, 0.93 between RPE and VO_2, and 0.89 between HR and VO_2.

Table 3. Results of correlational analysis

	ρ (Borg)	ρ (Dial)
RPE/HR	0.85*	0.92*
RPE/VO_2	0.91*	0.93*
HR/VO_2	0.92*	0.89*

ρ = Spearman rho correlation coefficient
* = Significant relationship between variables ($p < 0.05$)

F tests were performed to determine if significant differences existed between correlation coefficients from the Borg scale and the dial. A critical F value (26,26 = 2.58, alpha = 0.02) was established, and F values for these tests were 1.091 for RPE/HR, 1.019 for RPE/VO_2, and 0.9699 for HR/VO_2. Results of the tests revealed no significant differences between correlation coefficients from the Borg and analog dial groups.

DISCUSSION

The purpose of this investigation was to test a new method of obtaining RPE during treadmill exercise. This was done by comparing the new method with a technique which has been previously found to be valid and reliable, the Borg 15 point rating scale of perceived exertion. Both scales were highly correlated with the physiological variables of HR and VO_2. Further, the analog dial appeared to have similar correlation values to those obtained with the Borg scale.

Several studies have revealed results similar to those found in this investigation. Bar-Or, Skinner, Buskirk, and Borg (3) determined the relationship between RPE and HR during bicycle and treadmill exercise in 41 to 60 year old men who varied in conditioning level and in body fatness. The investigators found correlation coefficients of 0.77 and 0.80 for the bicycle and the treadmill, respectively. Eston and Williams (11) found a slightly lower relationship between RPE and HR for bicycle exercise in adolescent boys ($r = 0.74$). The highest correlation between RPE and HR ($r = 0.95$) was found during rowing ergometry (18). Another high correlation was discovered by Gamberale (12). He found a coefficient of 0.94 in male university students during cycle ergometry. A correlation of 0.84 was found for Japanese male adolescents during submaximal treadmill running (19). Lastly, Smutok, Skrinar, and Pandolf (28) determined correlation coefficients to be 0.85-0.87 for three trials of treadmill exercise.

This study revealed correlation coefficients between RPE and VO_2 of 0.91 and 0.93 for the Borg scale method and the analog dial method, respectively. These values are slightly higher than those found by most researchers.

Smutok et al. (28) found a correlation coefficient of 0.87 between RPE and VO_2 during treadmill exercise. This value closely approaches those found by Edwards, Melcher, Hesser, Wigerbtz, and Ekelund, r = 0.88, (9) and Sargeant and Davies, r = 0.92, (24). Goslin and Rorke (13) observed a lower relationship between RPE and VO_2. They studied these variables during backpack load carriage, for college age men, and found correlations of 0.71 and 0.80 at two different speeds. In an investigation using Japanese male subjects (19), a correlation of 0.76 was determined.

The literature suggests that the RPE/VO_2 relationship is not as strong as the RPE/HR relationship. Kamon, Pandolf, and Cafarelli (16) and Toner, Drolet, and Pandolf (30) found much lower correlations than those studies described above and the current investigation. A correlation coefficient of 0.52 was observed during cycle ergometry (16), and during water exercise a value of 0.51 was found (30). A possible reason for the lower correlation during water exercise may be the cold environment in which the subjects were tested (20^{o}C). The results of this investigation further support the majority of research which demonstrates a fundamental relationship between RPE and VO_2.

Rating of perceived exertion is used as an adjunctive measure to physiological functioning such as HR and VO_2. Along with this application, perceived exertion can be analyzed as a separate measure. This can be done by examining the progression of RPE throughout incremental exercise. Several studies have analyzed this, and have found a linear relationship between Borg scale RPE and workload (7,8,11,20,25,26,28,31). The results of the present study support this finding. Appendix G presents a scatter plot of Borg scale RPE and percent of the graded exercise time. One hundred percent of the graded exercise time represents maximal exertion or the endpoint of the test. This plot graphically demonstrates linearity.

It was stated in the introduction of this investigation, that utilizing an analog scale to assess RPE may result in a more in-depth analysis of subjective feelings during exercise. Appendix H represents a scatter plot of RPE, obtained from the analog dial, and percent of the graded exercise time. Graphical interpretation of this figure suggest that a curvilinear relationship exists between variables.

Similar curvilinear relationships between RPE and physiological variables have been observed by other researchers. Skrinar, Ingram, and Pandolf (27) found a curvilinear relationship between RPE and epinephrine and norepinephrine for women during treadmill exercise. Moreover, Skrinar et al. (27) found a quadratic trend between RPE and blood lactate levels during exercise.

The present investigation suggests two points. First, analog RPE correlates significantly with the physiological variables of HR and VO_2, but not significantly better than Borg scale RPE. Second, the analog scale shows a curvilinear relationship with percent of the graded exercise time.

It is suggested that further research in RPE techniques which utilize analog dial scales be conducted to investigate the relationship between RPE and physiological variables and workload. Special attention should be paid to reliability, validity, and linearity.

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APPENDIX A

REMINDER

Rating of Perceived Exertion Study

REMINDER

Dear ________________,

You have agreed to participate in a study of perceived exertion on ___________. Your participation will involve performing a treadmill exercise test. This test will be performed in the Human Performance Laboratory which is located in Room 225 Mitchell Hall. The time which you have previously signed up for is __________. Your promptness is appreciated.

You should abstain from food, tobacco, alcohol, and caffeine for at least three hours prior to testing. Clothing should permit freedom of movement and should include comfortable running shoes.

If you have any questions, please feel free to contact me at 784-8676.

Thank You!

APPENDIX B

HEALTH HISTORY QUESTIONNAIRE

HEALTH HISTORY QUESTIONNAIRE

Name:__________________________ Date:_____________

Please answer yes or no to the following questions. If your answer is yes, please elaborate in the space provided.

1. Has your doctor ever told you to only exercise under his/her supervision?

2. Have you ever felt any pain in your chest during physical activity?

3. In the past four weeks, have you had any chest pain when you were not doing physical activity?

4. Do you ever lose consciousness or have dizzy spells?

5. Do you have a bone or joint problem?

6. Are you currently on any doctor prescribed medicine?

7. Is there any other reason why you should not do physical activity?

APPENDIX C

INFORMED CONSENT

The Testing of a New Method for Collecting Rating of Perceived Exertion Data During Treadmill Exercise

INFORMED CONSENT

I, ________________________, give my informed consent to participate in this study to test a new method for obtaining rating of perceived exertion (RPE). I consent to publication of study results so long as the information is anonymous and disguised so that no individual identification can be made. I further understand that although a record will be kept of my having participated in the experiment, all experimental data collected from my participation will be identified by number only.

I have been informed that my participation in this experiment will involve my performing a maximal treadmill exercise test to volitional exhaustion. During the test I will have to breathe through a mouthpiece for the collection of oxygen, and wear a heart rate monitor.

I have been informed that the general purpose of this experiment is to determine if the conventional method or the new method of obtaining RPE yield truer data.

I have been informed that during the exercise test, I may feel tired, light headed, or experience shortness of breath. Tripping, fainting, or falling may also occur resulting in injuries such as sprains, strains, or broken bones. There is also the rare possibility of heart attack or stroke. These risks and discomforts will be minimizes by having only trained personnel administer the exercise test.

I have been informed that there are no "disguised" procedures in this experiment. All procedures can be taken at face value.

I have been informed that the investigator will gladly answer any questions regarding the procedures of this study when the experimental session is complete.

I have been informed that I am free to withdraw from the experiment at any time without penalty of any kind.

Concerns about any aspects of this study may be referred to Matthew Washburn at 784-8676, or Dr. Richard Mikat at 129 Mitchell Hall or 785-8182.

________________________ ________________________

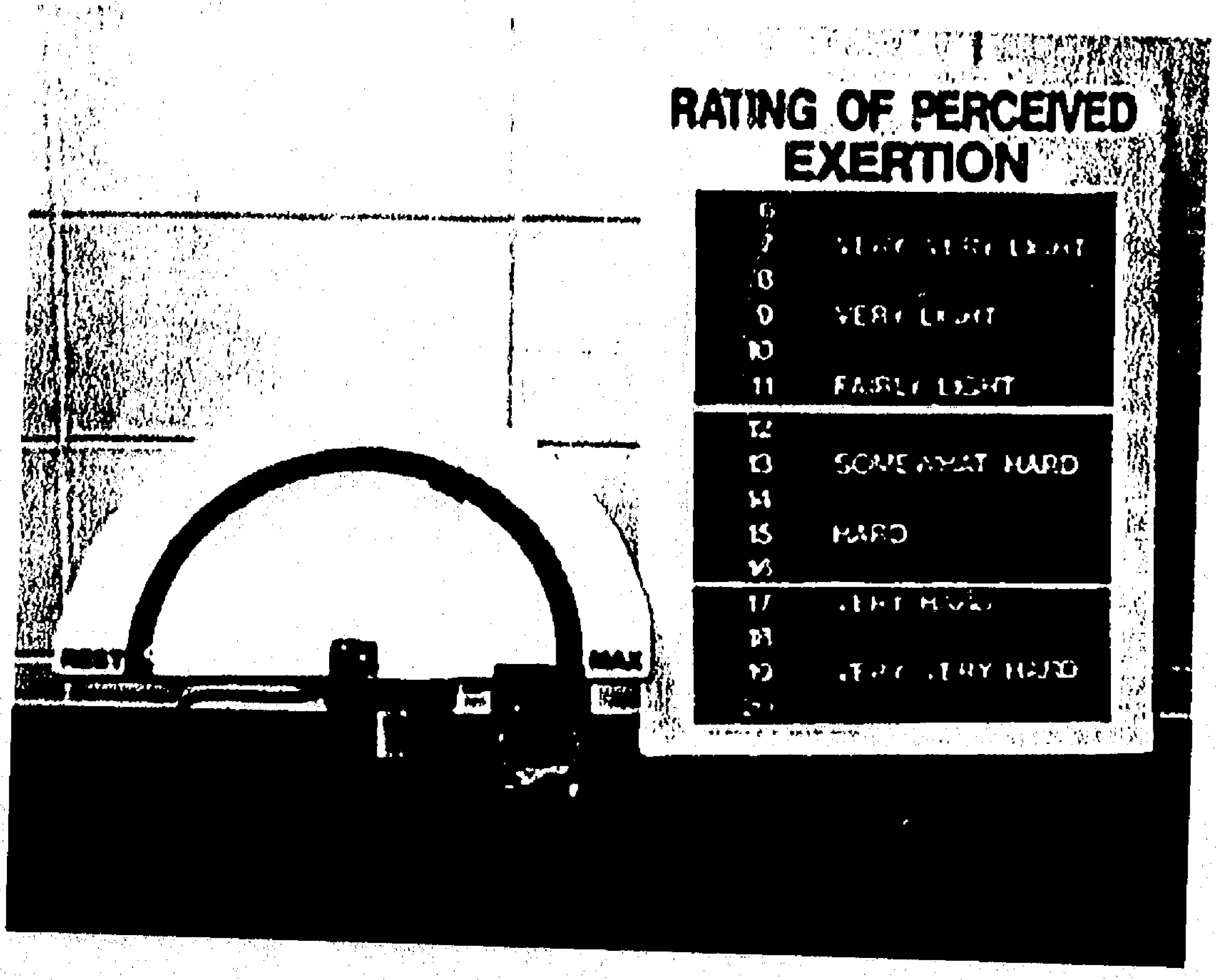
Experimenter Experimental Participant

____

Date

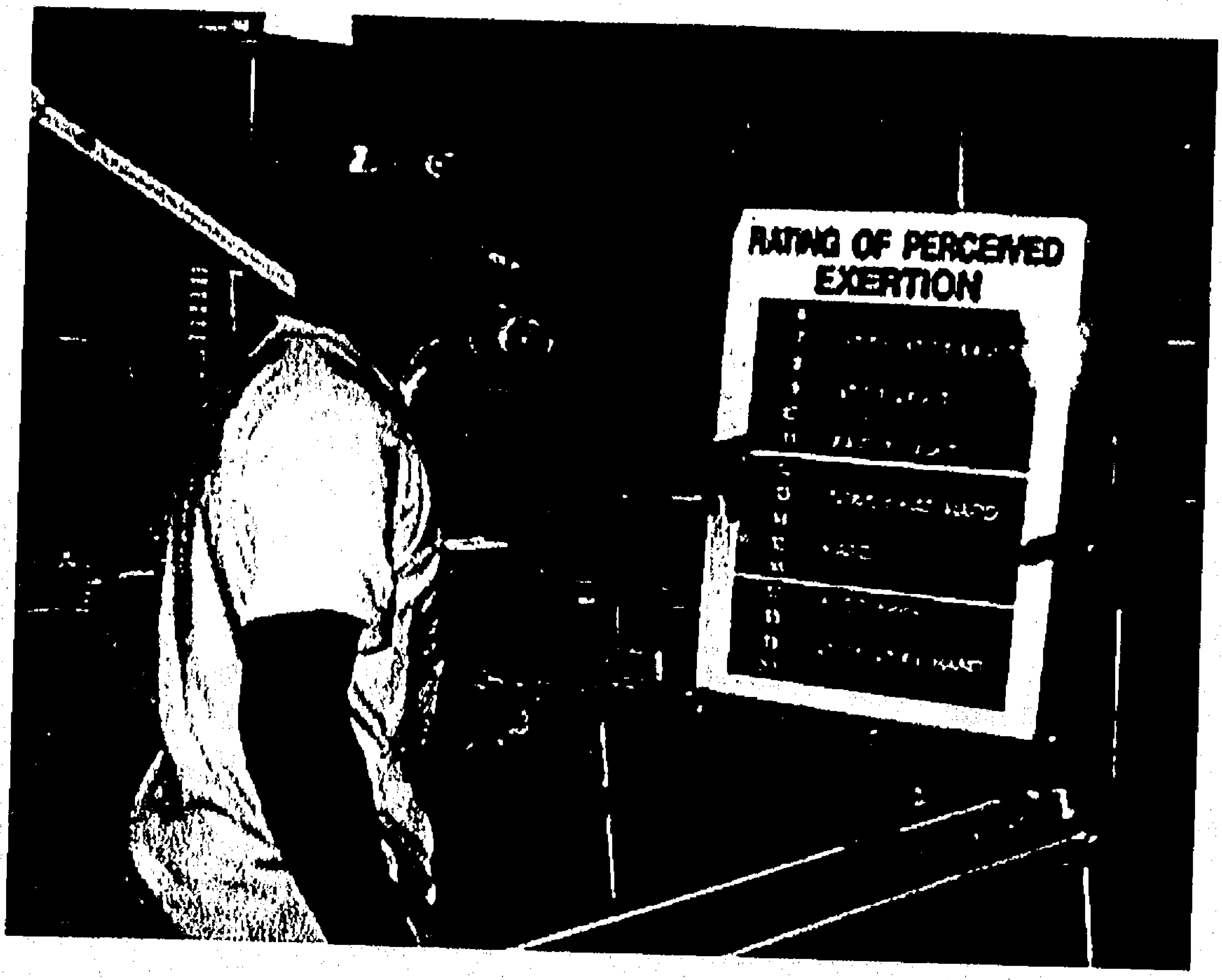
APPENDIX D

RPE METHODS


RATING OF PERCEIVED EXERTION
11 FAIRLY LIGHT
13 SOMEWHAT HARD
15 HARD
REST
MAX

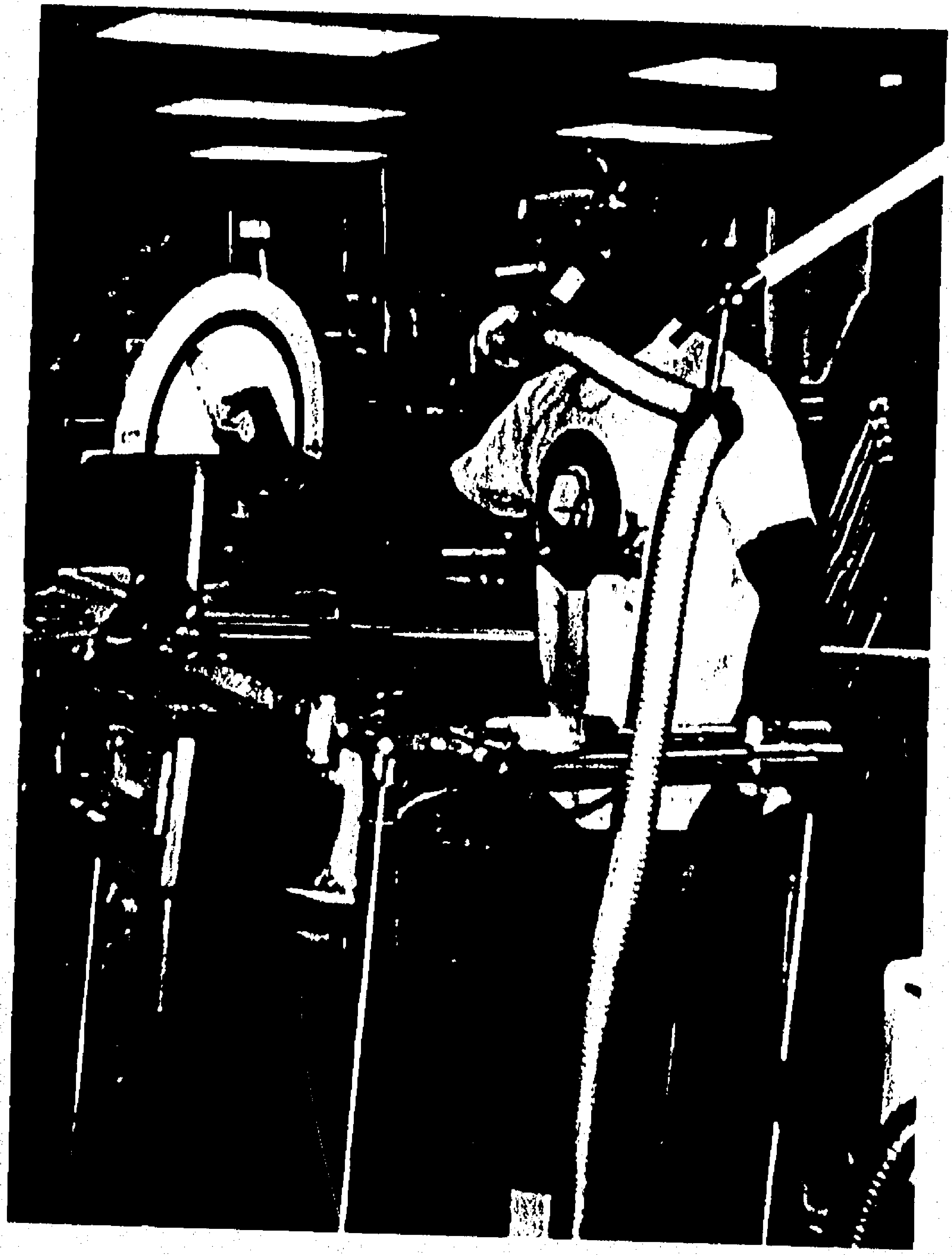
APPENDIX E

MANIPULATION OF THE BORG SCALE


RATING OF PERCEIVED
EXERTION

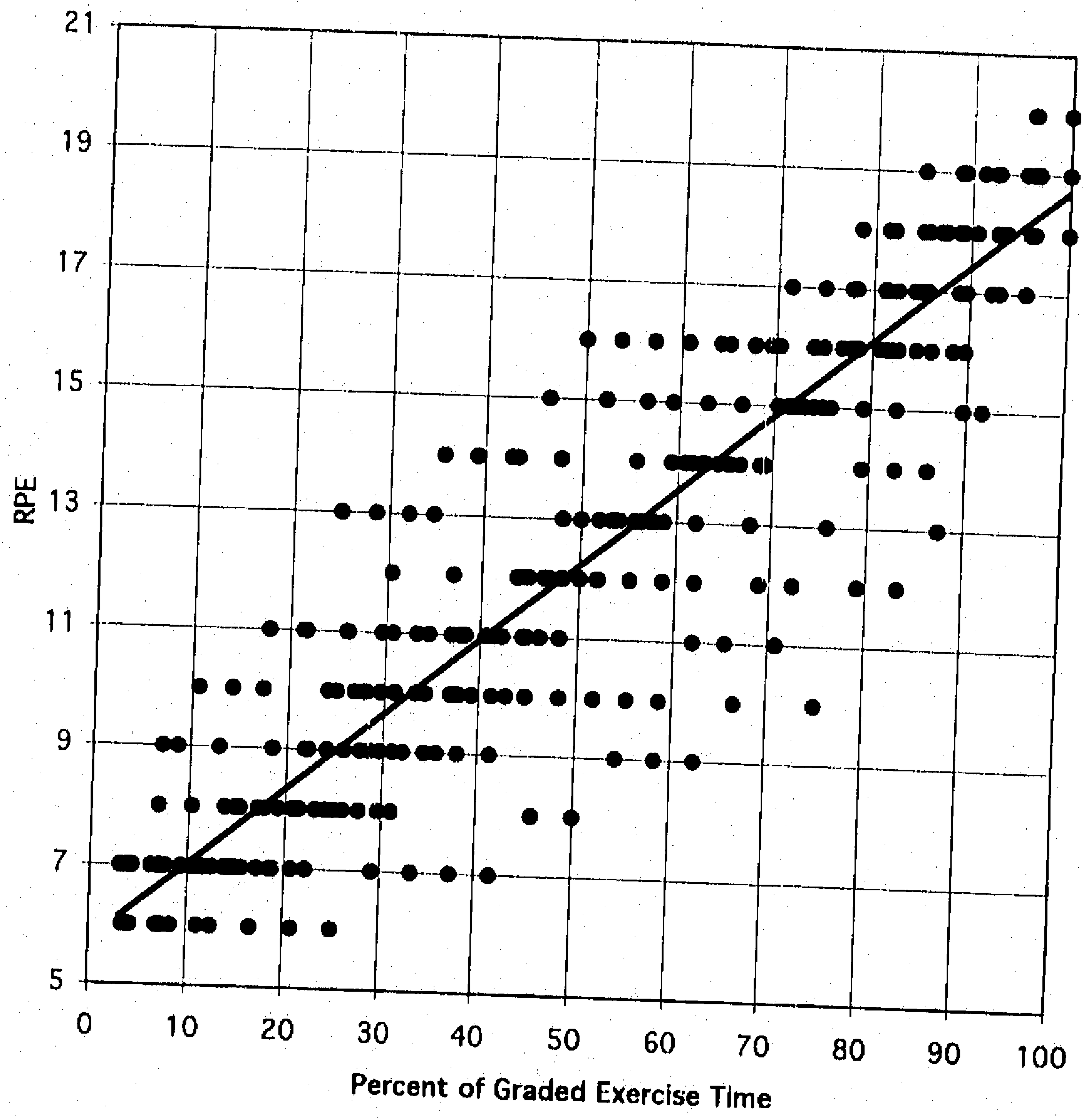
APPENDIX F

MANIPULATION OF THE ANALOG DIAL



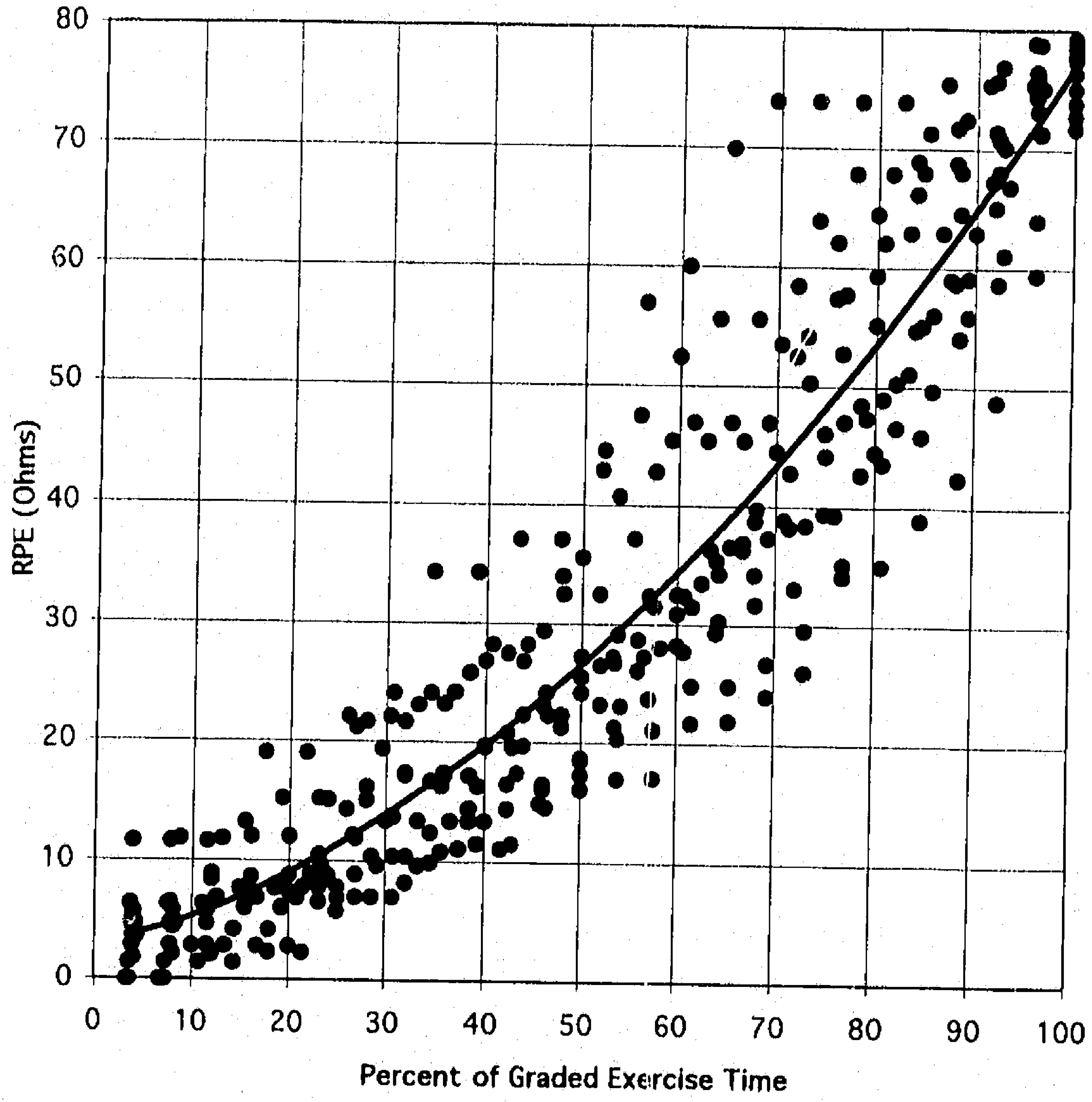
APPENDIX G

SCATTER PLOT OF RPE VS PERCENT OF GRADED EXERCISE TIME USING THE BORG SCALE


21
19
17
15
13
11
9
7
5
RPE
0
10
20
30
40
50
60
70
80
90
100
Percent of Graded Exercise Time

APPENDIX H

SCATTER PLOT OF RPE VS PERCENT OF GRADED EXERCISE TIME USING THE ANALOG DIAL


80
70
60
50
40
30
20
10
0
RPE (Ohms)
0
10
20
30
40
50
60
70
80
90
100
Percent of Graded Exercise Time

APPENDIX I

REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Subjective rating scales may be used to communicate sensations experienced during physical activity. Among these scales are the dyspnea scale, the angina scale, and the claudication scale (2). The most frequently used subjective rating scales measure perceived exertion during exercise. These scales translate subjective feelings of physiological stress into objective pieces of data.

Physiological and Psychological Basis of Perceived Exertion

Exercise perceptions emanate from a variety of physiological and psychological sources. The physiological factors which influence perceived exertion include respiratory/metabolic, peripheral, and nonspecific mediators (39).

Respiratory/metabolic signals are mediated by ventilatory drive (53), oxygen consumption (19,22,49,52), carbon dioxide excretion (11), heart rate (18,19,30,46,49), and blood pressure (26). Peripheral signals occur through physiological events in active muscles and joints (39). These events include metabolic acidosis (28,41), lactic acid accumulation (1,37,54), fast and slow twitch contractile properties of skeletal muscle fiber (29,37), muscle blood flow (12), and blood borne energy substrates (44). The nonspecific mediators include catecholamine secretion (48), temperature regulation (21,46), and exercise induced pain (7).

The psychological factors which influence perceived exertion can be explained under two broad categories. These are situational and dispositional factors (39).

Situational factors include expected duration (40), expected performance (55), the degree to which one values presenting oneself in a socially desirable manner (8,10), and attentional focus, or the manipulation of sensory cues to control conscious awareness (9,25).

The influence of dispositional factors on perceived exertion include the process by which one regulates sensory input (42), the degree of femininity or masculinity that can be identified in both men and women (23), cognitive style (35,45), self-efficacy (33), and personality (34).

Methods of Obtaining Perceived Exertion

The first known rating of perceived exertion scale was developed by Gunnar A. V. Borg (39). He measured this 0-20 point perceived exertion scale with heart rate and power output, but did not prove it to be linearly related to either (39). Borg then redesigned the scale with a range of 6-20 points (4). This new 15 point scale is widely used and has been found to be linear and highly correlated with physiologic functioning (17,18,19,22,30,38,46,52).

Another scale with fewer categories was developed at the University of Pittsburgh in the early 1970s (39). This 1-9 point scale had point 2 anchored with the expression "not at all stressful" and point 8 with the expression "very, very stressful." The justification for the additional category below 2 and above 8 is that it is very possible the subjects can experience sensations greater than what they thought to be maximal exertion and less than they thought to be no exertion at all (31). Two studies, each using cycle ergometry, suggest the 9 point scale is reliable and may be used as a valid predictor of heart rate and power output (43,51).

Another scale utilized an 11 cm line (39). The expression "no exertion at all" was written on the left and "maximal exertion" was written on the right. The subjects mark the line, by pencil, to indicate how far the exertion has progressed from "no exertion at all."

Borg (5) produced a study in which the four category scales previously discussed were compared. That is the 21 point scale, 15 point scale, 9 point scale, and line scale. Two separate tests were performed using a cycle ergometer. In the first test, subjects rode the cycle ergometer to exhaustion at a constant power output of 1400 kpm/min. Perceived exertion and heart rate were obtained every 2 minutes. The second experiment consisted of a maximal exertion graded exercise test in which workload started at 600 kpm/min and increased 300 kpm/min every 6 minutes. The data were analyzed using correlation tests between heart rate and perceived exertion.

Results of the first test showed correlation coefficients for the 21 point, 15 point, 9 point, and line scales to be very similar at 0.56, 0.62, 0.54, and 0.61 respectively. Corresponding coefficients for the second work test were reported to be 0.61, 0.72, 0.52, and 0.63 respectively. Borg concluded that good correlations between heart rate and perceived exertion ratings can be obtained independently of which scale is used, and that there is a fundamental relationship between physiological indicators of physical stress and psychological indicators.

Another perceived exertion scale which has been developed for use in ergonomics utilizes a seven point scale. Hogan and Fleishman, who developed the scale, examined it in two investigations (24). The results of the first study revealed that ratings of effort were highly correlated with actual metabolic costs for trained people ($r = 0.81$, $p < 0.01$). The second study examined sex differences in ratings of perceived effort using untrained people. Resulting correlations for men ($r = 0.80$, $p < 0.01$) and women ($r = 0.70$, $p < 0.01$) indicate that ratings of perceived exertion are good predictors of metabolic costs in task performance. The study also demonstrated that no significant differences across tasks existed between men and women.

The final, and most recently developed, rating of perceived exertion scale is the 0-10 point category ratio scale presented by Borg (6). The relationship between this scale and lactic acid accumulation, as well as heart rate, was studied by Noble, Borg, Jacobs, Ceci, and Kaiser (37). It was shown that perceptual ratings and blood lactate both increased with a similar quadratic (square) trend, muscle lactate showed a cubic trend, and heart rate showed a linear trend.

<u>Validity and Reliability of Borg's Rating of Perceived Exertion Scale</u>

Validity and reliability must be established in order for any measurement tool to be accepted for scientific use. Numerous studies have tested the reliability and validity of Borg's 15 point exertion scale. Although many different methods of acquiring perceived exertion during exercise have been developed (4,6,24,39), the Borg scale is the major measurement technique utilized by exercise scientists and clinicians (39).

Reliability

The initial study which tested the reliability of Borg's rating scale of perceived exertion was undertaken by Skinner, Hutsler, Bergsteinova, and Buskirk (47). The scale was tested using 16 male subjects, 8 lean and 8 obese. Subjects performed 2 trials on a bicycle ergometer using 2 different protocols. One utilized a random order protocol, while the other utilized a progressive protocol. Correlation coefficients for the progressive and random tests were 0.80 and 0.78, respectively.

Smutok, Skrinar, and Pandolf (49) had subjects exercise on a treadmill at five progressive speeds, obtaining perceived exertion and heart rate at each speed. Subjects were than asked, on two separate occasions, to subjectively regulate their own treadmill speed at the perceived exertion reported for each speed during the first trail. Correlation coefficients between rating of perceived exertion and speed, and rating of perceived exertion and heart rate for each trial were 0.83-0.85 and 0.85-0.87, respectively.

Reliability was also tested by Bar-Or, Skinner, Buskirk, and Borg (3). They studied the relationship between heart rate and perceived exertion for treadmill and cycle ergometer exercise. Correlation coefficients between heart rate and perceived exertion were determined to be 0.77 and 0.80 for the bicycle and the treadmill, respectively.

Another assessment of the reliability of the Borg scale was overseen by Stamford (50). Fourteen college age, sedentary females volunteered to participate in the experiment. Subjects completed bicycle ergometer tests arranged in progressive and random order, treadmill walking at a submaximal intensity, and stool stepping tests. Ratings of perceived exertion were requested at the end of each work intensity. Test-retest reliability coefficients were 0.90 for the progressive bicycle test, 0.71 for the random test, and 0.76 for both the stool stepping exercise and the submaximal treadmill walking task.

Validity

Skinner et al. (47) examined the validity of Borg's perceived exertion scale. They did this by having subjects cycle using both progressive and random protocols. The results showed that there were no significant differences ($p > 0.05$) between the perceptual ratings for the protocols.

Stamford tested the validity of the Borg scale by examining heart rate/perceived exertion plots (50). While there was high interindividual variability with respect to heart rate at a given workload, a highly linear relationship between heart rate and rating of perceived exertion was demonstrated when mean responses were considered. Stamford concluded "The rating of perceived exertion scale is supported as a valid and reliable instrument for the assessment of the degree of encountered stress during work effort (50, p.59)."

Other studies have also tested the validity of the Borg scale by showing a linear relationship between rating of perceived exertion and heart rate (18,19,30,38,46,52), and rating of perceived exertion and oxygen consumption (17,19,22,46) during different modes of physical activity.

Perceived Exertion and Graded Exercise Testing

Ratings of perceived exertion are most frequently used during graded exercise testing as an adjunctive measure of functional exercise tolerance (39). Since exertional perceptions are related to respiratory/metabolic and peripheral physiological mediators, rating of perceived exertion provides a subjective measure of exercise tolerance that complements objective physiological measures (39).

In order for a graded exercise test to be judged valid, perceptual and physiological responses must be linearly related across a variety of intensities (39). Gamberale (19) examined this linearity using a maximal cycle ergometer test given to 12 college age males. Each subject exercised for 6 minutes at workloads of 300, 600, and 900 kpm/min and at a workload which was predicted to exhaust the subject in about 5 minutes. Heart rate, oxygen uptake, blood lactate, and perceived exertion were determined during the last minute of every exercise period. Results showed that rating of perceived exertion increased linearly with all variables, and the correlation coefficient between perceived exertion and heart rate was computed at 0.94.

The relationship between rating of perceived exertion, heart rate, and oxygen consumption has also been evaluated graphically by Skinner, Hutsler, Bergsteinova, and Buskirk (46). It was found to be a linear relationship for bicycle and treadmill exercise, in different environmental temperatures, and for lean and obese individuals.

Perceived exertion is also a valuable guide as to the progression of a graded exercise test. The increment in rating of perceived exertion from one test stage to the next can be used to estimate rate of progress toward the test end point. When the highest scale category is reported, it provides subjective confirmation that physiological end points of the test have been achieved (39).

Noble (36) states that as a general rule, people will not be able to complete more than one additional stage of the Bruce treadmill protocol after responding with a perceived exertion of 15 on the Borg scale. Also, Smutok et al. (49) found that on a horizontal treadmill, a walking speed increment of 1.7 km/hr elicited a perceived exertion increase of two rating units, while increments of the same amount during running produced a one unit increase on the Borg scale of perceived exertion. Likewise, Kamon, Pandolf, and Cafarelli (27) showed that during cycle ergometer testing, an increment of 300 kgm/min elicited a one unit increase.

Perceived Exertion and Exercise Prescription and Regulation

Exercise prescription can be based on physiological responses (such as oxygen consumption or heart rate), clinical responses (such as electrocardiogram abnormalities or blood pressure abnormalities), or perceptual responses (such as rating of perceived exertion) (2). Since rating of perceived exertion is functionally related to physiological and clinical responses, it may be used for both the prescription and regulation of exercise intensity (39).

Dishman, Patton, Smith, Weinberg, and Jackson (14) performed an extensive study which examined feedback of heart rate and heart rate combined with rating of perceived exertion. These researchers examined which type of feedback, during a graded exercise test and during early trials of field training, would reduce the errors commonly seen when training heart rate range is self-monitored by participants. Thirty male subjects were randomly assigned to three groups: control, heart rate feedback, and rating of perceived exertion and heart rate feedback. All subjects were given a modified Balke treadmill test. The control group was given no feedback, while the heart rate feedback group was informed when their heart rate was ten and five beats below, equal to, and five and ten beats above a previously calculated target heart rate. The subjects in the heart rate and rating of perceived exertion group were given the same heart rate feedback as the previous group, and statements of perceived exertion using Borg's 6 to 20 point category scale were elicited within five seconds of each corresponding heart rate feedback.

Following the graded exercise test, but on separate days, all subjects performed three trials of an 800 meter walk/jog. Each group was instructed to achieve a training heart rate representing 60% of the available heart rate range as determined through the treadmill test. Heart rates were obtained by experimenter's palpation of carotid pulse immediately upon completion of the exercise. Control subjects were instructed how the training heart rate was calculated but not told their number. Subjects in the heart rate group were instructed to attempt to reproduce their training heart rate based upon memory of the heart rate feedback from the exercise test. The subjects in the combined heart rate and perceived exertion group were instructed to attempt to reproduce training heart rate based upon memory of the heart rate and rating of perceived exertion feedback during the treadmill test, and were given a card with the Borg scale. All subjects were provided with heart rate feedback following each field trial so that intensity might be adjusted appropriately for the next trial.

Results of the study suggest the graded exercise test learning protocol combining heart rate and rating of perceived exertion feedback was effective ($p < 0.05$) in reducing training heart rate overestimates during the first day of field training. Also, trial three showed a marginally significant ($p < 0.06$) difference between rating of perceived exertion and heart rate group when contrasted with the control group.

Research has also been performed on the regulation of exercise intensity by perceived exertion for treadmill cycle ergometer exercise (15). It was found that rating of perceived exertion is a valid tool for the regulation of exercise intensity during treadmill exercise only. This was shown by the oxygen consumption and heart rate values not differing from the target values at any time during treadmill work. These findings are supported by other studies including those by Dunbar et al. (16), Glass, Knowlton, and Becque (20), and Chow and Wilmore (13).

The relationship between ratings of perceived exertion and exercise levels in rowing ergometry has been studied by Marriott and Lamb (32). They used nine competitive male rowers. Each rower completed two exercise sessions on a Concept II model B rowing ergometer. The first session consisted of an incremental protocol designed to elicit a range of work outputs and heart rates. At each intensity level, perceived exertion was indicated using Borg's 15 point scale. The second session, which occurred 7 to 14 days later, consisted of the subjects reproducing exercise intensities corresponding to rating of perceived exertion values of 15, 11, 17, 13, and 19. Results of the study revealed high correlations between heart rate and perceived exertion ($r = 0.95$, $p < 0.01$) and work output and perceived exertion ($r = 0.96$, $p < 0.01$).

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